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# Activated Carbon Filters

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# Agricultural Engineering Update



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AEU - 46

## Activated Carbon Filters

by

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University of Kentucky

Many people feel the water supplied by public water systems to their home faucets is not safe. Most people judge the quality of their water by taste, odor and appearance. But the risk to one's health cannot be judged by these factors. Many of the chemicals or biological organisms that affect one's health are tasteless, odorless and cannot be seen. In searching for a means to improve the safety to their drinking water they encounter water filters, water purifiers, activated carbon (AC) filters that are common names for home drinking water treatment devices. In reading the labels, boxes and instructions on these devices to choose a reliable device, a consumer can become confused as to what the devices are able to remove from the water, by what means do they remove contaminants and how reliable these devices are. The U.S. Environmental Protection Agency (USEPA) has defined three general categories of home drinking water treatment devices.

1. Water filters are generally comprised of activated carbon (AC), make no claims for pesticidal (antimicrobial) activity, and are intended to remove rust, sediment, organic compounds that impart a taste, odor or color, chlorine, and/or certain other selective organic contaminants. They do not, however, remove or destroy bacteria.

2. Bacteriostatic water filters are also generally comprised of AC and remove the same undesirable contaminants as the water filters but, additionally are impregnated with a chemical agent such as silver ions to hinder the growth of bacteria that may become trapped by the filter. (Bacteriostatic means the ability to inhibit the further growth of bacteria. Some chemicals can be added to the filter to inhibit bacterial growth. For instance, silver is often added to a filter to keep down bacterial growth within the filter. The label can then state "inhibits bacterial growth within the filter medium".)
3. Water purifiers are designed to treat raw water of unknown quality and render it suitable for human consumption. A purifier, by definition, must kill or remove essentially all bacteria, protozoa and/or protozoan cysts that are present that the label or instructions claim to remove. These products are further subdivided as (a) pesticidal devices where purification is brought about purely by physical or mechanical means such as filtration, heating, etc., where no antimicrobial chemical agent is involved and (b) pesticides where purification is achieved through the use of antimicrobial agents incorporated within the product. (The word pesticide or pesticidal is not to be confused with chemicals used in agriculture or households to control weeds, insects, molds or bacteria. The word is the general form meaning an agent that destroys a pest. In this case the pest is human pathogenic bacteria protozoa and protozoan cysts).

If a manufacturer claims that a unit will inhibit or reduce the growth of bacteria or other microorganisms and the unit contains a chemically active ingredient to do so (i.e. bacteriostatic water filters and pesticidal or pesticide devices), then the unit and the manufacturer are required to be registered with the USEPA before the devices can be legally held or offered for sale. In addition Facilities producing bacteriostatic water filters and pesticidal devices, and pesticides are required to show a USEPA establishment registration number. This establishment registration number indicates that the facility producing the unit deals with pesticides and that it is subject to USEPA routine investigations with respect to recordkeeping, production, storage, shipping procedures, etc.

If a manufacturer claims that a unit will inhibit or reduce the growth of microorganisms but no chemically active ingredient is used, then only the manufacturer must be registered. If a manufacturer does not make any claims to inhibit or reduce microorganism growth, then neither the unit nor the manufacturer must be registered. This registration does not imply any USEPA approval of the unit nor its effectiveness for the manufacturer's stated purpose. The registration means:

- The manufacturer claims that the unit has some sort of pesticidal property.
- Under normal use the pesticidal agent will not leach out of the unit in concentrations which would be harmful to humans.

The registration does not mean:

- The unit is in any way endorsed or approved by EPA as a water treatment device.
- The unit is in any way superior or inferior to any other unit.

Particulates or sediments are removed by a mechanical process due to physical size. Two type filters exist: a depth filter and a surface filter. A depth filter consists of an array of fibrous, granular or sintered material that is wound pressed or bonded together. The size opening between the material decreases with depth with particulates being trapped throughout the depth. The depth filter has a nominal or approximate rating of the particle size that it will remove. The rating is in microns (1 micron = .00004 inches). The micron rating is not an absolute minimum size of particulates retained by the depth filter. Some particles larger than this size will pass through and some particles smaller than the size will be retained. What this percentage is cannot be stated. Depth filters in general are used when particulate loads are high or when retaining a large amount of particulates without the filter clogging.

Surface filters trap particulates at or very near the material surface. They function like a screen and precision openings in the filter can be manufactured. The rating or minimal retained particle size can be defined more precisely. But these filters clog more readily. Usually they are preceded by a depth filter. Membrane, pressed fiber, ceramic coated or resin bonded filters fall into this category. An opening size (e.g. .3 microns) can be precisely made to filter out bacteria, protozoa, spores and cysts. These will be retained on the surface by these filters and not pass through (pesticidal device). Viral particles though will pass through since a virus can have a size of .01 microns.

The majority of water filters purchased today contain activated carbon or charcoal (AC) as a powder granules, solid block, paper membrane or wound spool made of carbon impregnated cotton cord or foam. Some devices contain AC but make no claim of it being present, further some devices claim removal of odor and taste but do not mention whether AC is present and the only way of determining its presence may be to break open the devices.

AC is a form of carbon that is modified by a carefully controlled oxidation process to develop a porous carbon structure with a large surface area. Some of the raw materials are coal bones, wood, nut shells, peat, lignite and residue from petroleum processes. The lattice of internal microscopic passages gives AC an immense surface area. A single gram of AC can have a total surface area of more than 1000 sq ft. AC is extremely adsorptive. It can effectively remove organic compounds, chlorine and dissolved radon. Carbon filters will not remove bacteria, calcium and magnesium (hard water), fluorides, nitrates, chlorides. They remove a very small percentage of inorganic chemicals. As of this date no substantiation of the percentage of removal of inorganic chemicals has been found.

The molecules that are removed diffuse into the AC pores and eventually stick to the internal surfaces (See Figure 1). Smaller molecules will diffuse deeper into AC and can adsorb on more surface area than large molecules because of the size of the pores. All compounds are not adsorbed onto the AC surface equally. Chemicals which are the least soluble in water (high molecular weight, low polarity, less ionic) have greater adsorption onto the AC.

The effectiveness of removal of compounds by AC decreases with increased temperature because compounds adsorptivity is reduced, particulates may clog the pores, and bacteria growing on the AC will also clog the pores. The number and kind of compounds in the water will affect the ability of the AC to remove compounds. A compound that has a higher affinity for adsorption on AC than a compound already adsorbed may replace the already adsorbed compound. The parallel to this process can be seen in the water softening process using ion exchange resins. The resins are recharged by passing a high concentration of sodium (Na) ions over the resin bed replacing the magnesium (Mg) and calcium (Ca) ions in the resins because the Na has a higher affinity when it is at very high concentration. When Na is at a low concentration in hard raw water, the Mg and Ca ions have a higher affinity on the exchange resin and take the place of the Na ion on the resin. When an AC filter is nearly saturated with compounds, those compounds that have a low affinity for AC may not be adsorbed at all.

The type of material used to make AC affects its ability to adsorb chemicals as well as its total removal capacity. One measure of AC's capacity to remove organics is the iodine number. The iodine number is defined as the amount of iodine in milligrams, adsorbed by 1 gram of AC at a standard set of conditions. The higher the iodine number, the more adsorptive is the AC. It is rare to see such a number reported in the advertising literature, instructions or box labels of AC devices. Table 1 gives the iodine number for a limited number of AC filters.

There are four types of AC filters marketed as home treatment devices (see Figure 2A to 2D).

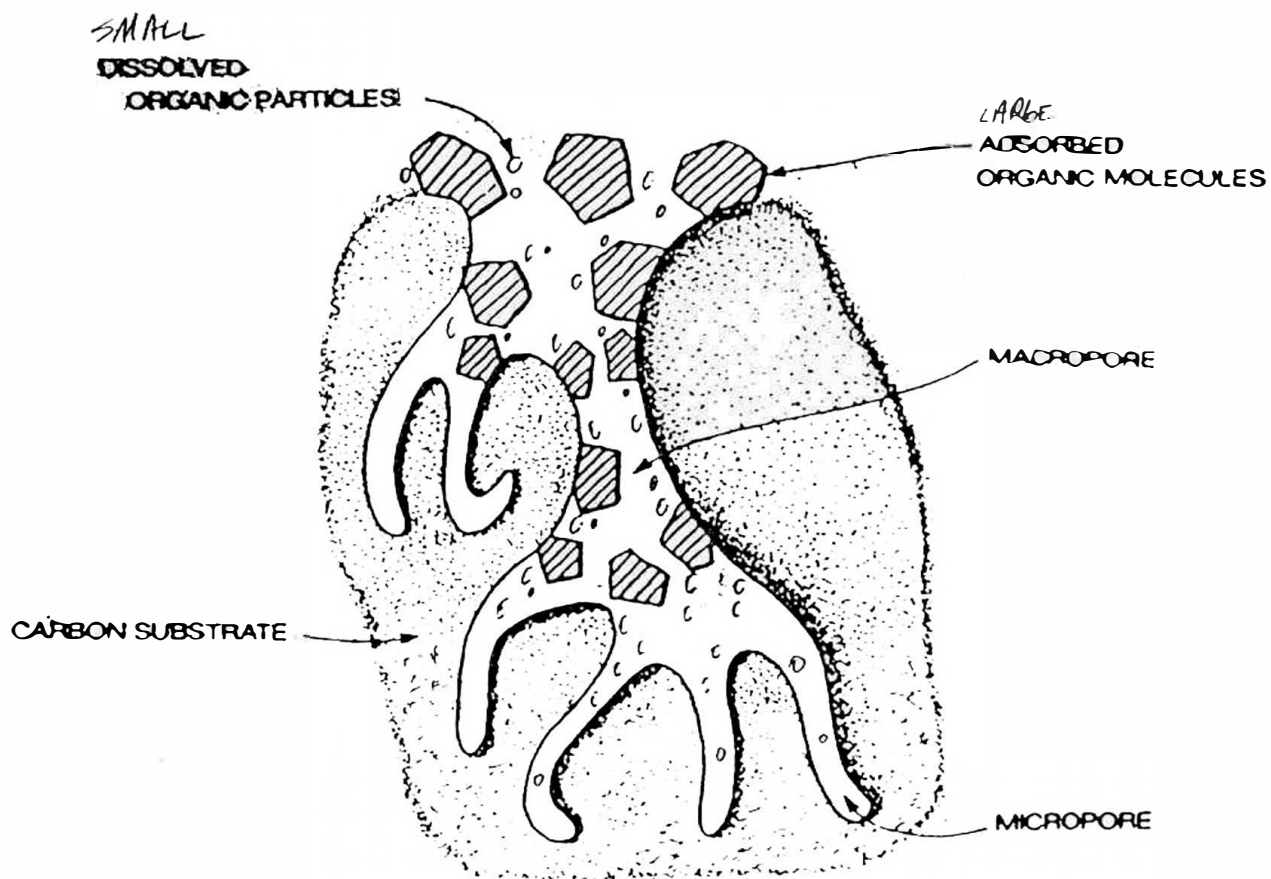


Figure 1. Representation of Activated Carbon Particle

- A) Faucet filters - slip over the mouth of the tap; 2 basic designs:
- 1) bypass - has a bypass valve that allows you to filter only the water used for cooking and drinking (prolongs the life of the filter).
  - 2) no bypass valve - all the water flowing through the tap is filtered.
- B) Pour-throughs - simplest, portable and require no installation at all. You simply hold the filter over a receptacle and pour tap water into the top.
- C) Stationary - tapped into the cold-water pipe so all the water flowing through the pipe is filtered. This type of filter with a larger rated capacity can be used to treat all the water as it enters the house.
- D) Line bypass - installed by cutting into the water line beneath the sink, but a separate faucet attached to the sink is used to deliver filtered water for drinking and cooking. Unfiltered water can still be drawn from the regular faucet.

How does a consumer choose an AC filter? There seems to be five factors that affect the ability of AC filters to perform their jobs.

- 1) water contact time with AC
- 2) iodine number (explained earlier)
- 3) particle size of the AC
- 4) manufacturers recommended water treatment capacity
- 5) independent organization rating and testing

Table 1 lists the contact times, the time it takes water to flow through the device, for a few of the AC filters for homes. Contact times can vary from 1 sec to 2 minutes based on information that is available. The longer the contact time, the more chance for the chemicals to diffuse into the AC to be adsorbed. The more AC in a treatment device seems to indicate more treatment ability (Table 1) if the flow rate of water (e.g. gallons per minute) are the same.

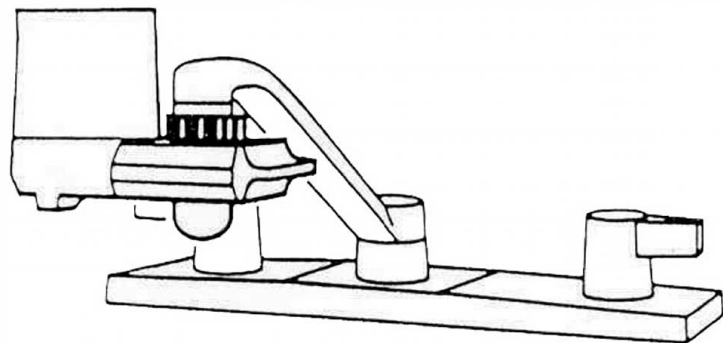
The particle size of AC affect the performance. The smaller the size, the more outside particle surface is available for compounds to enter the internal porous matrix of AC. The smaller the particles size of AC the higher the removal rate of organic contaminants. Therefore powdered AC and block AC, made from compressed powdered AC, would be more effective than granulated AC if the AC had the same iodine number, AC amount and contact time.

Table 1. GSRI Tests of Activated Carbon Treatment Devices for USEPA

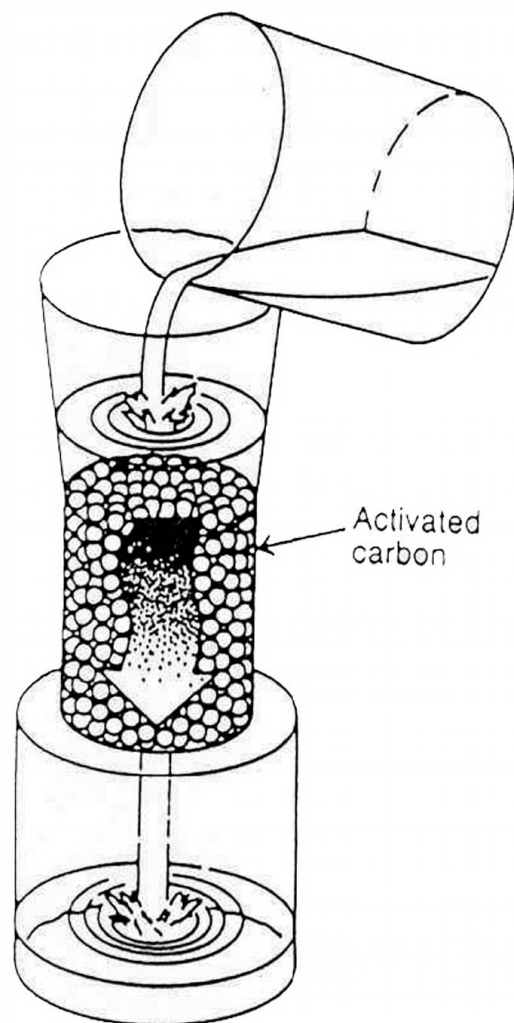
Unit	Manufacturer's rated capacity (gallons)	Amount of carbon (grams)	Iodine number of carbon	Contact time (seconds)	Average % Removal of THM	Average % Removal of NPT00	Average % Removal of Halogenated Hydrocarbons
<b>Line bypass</b>							
Culligan SC-2	4,000	1,708	980	39	89	28	99
Aquacell Bacteriostatic	2,000	417	867	13	86	23	97
Aqualux CB-2	2,000	1,150	966	35	98	23	99
Everpure QC4-THM	1,000	765	1,010	43	99	55	99
Seagull IV	1,600	300	434	15	70	41	97
<b>Faucet-mounted</b>							
Hurley Town & Country	4,000	895	913	36	69	31	97
Aqua Guard AGT31	500	51	1,275	3	43	12	
Instapure FI-C	200	27		1.6	24	11	
<b>Stationary</b>							
AMF Cuno-1M	3,000	395	870	3.6	34	7	
<b>Pour-through</b>							
Filbrook	1,000	97	788	44	40	14	94

(This is not a complete list from the study).



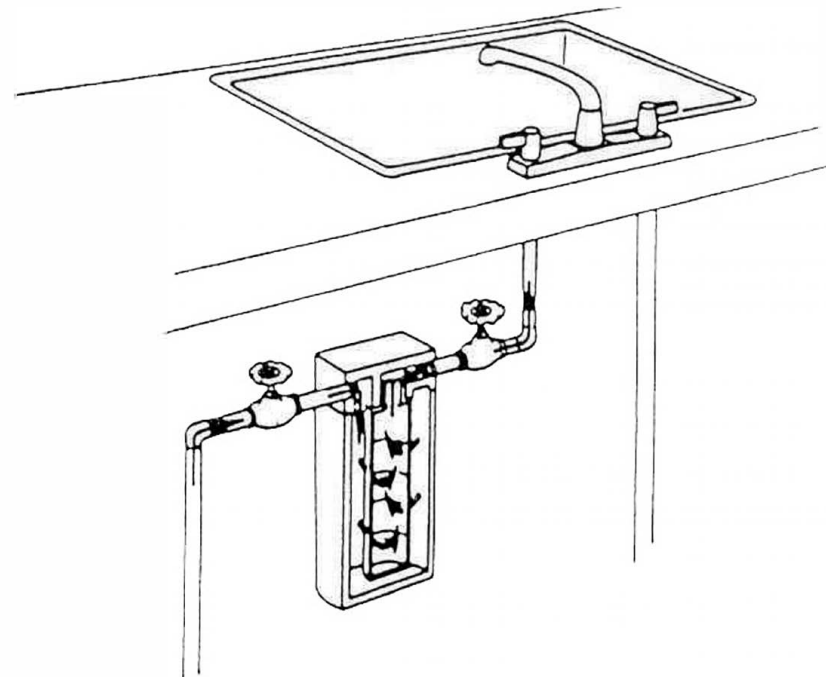


A

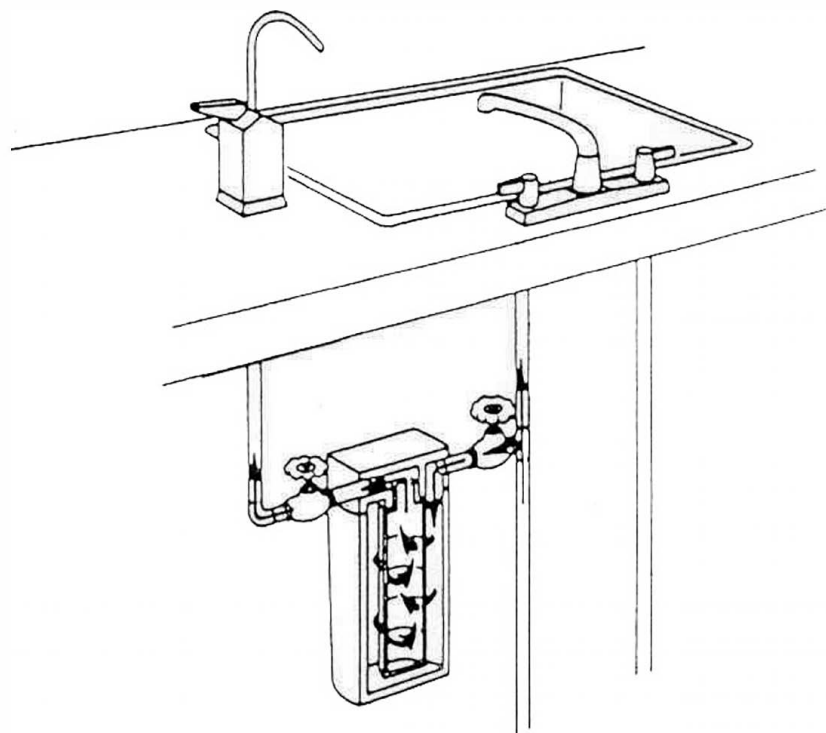


Activated  
carbon

B



C



D

Figure 2. Common AC Water Treatment Devices A) Faucet Mounted, B) Pour-Through, C) Stationary, D) Line Bypass

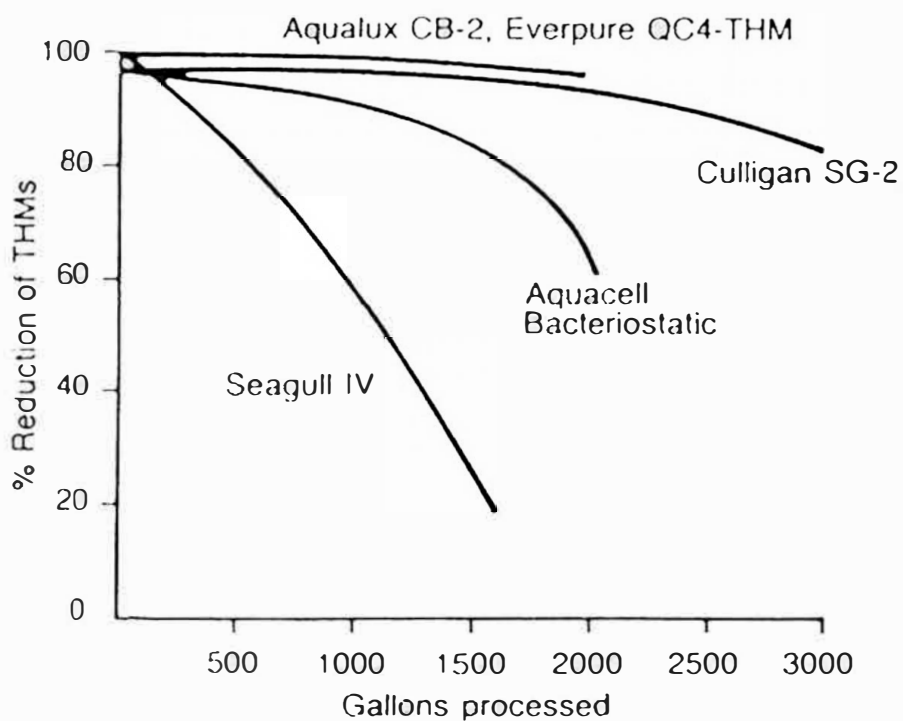
Some manufacturers of AC water treatment devices will give a recommended water treatment capacity in gallons. When the rated capacity is exceeded, the manufacturers recommend that the AC be replaced. Nearly all the devices on the market do not have a means of indicating how much water has passed through the filter. A consumer, though, can make an estimate of the number of days a filter will last before needing replacement. It is estimated that each person uses one gallon of water each for drinking and 1 to 3 gallons per day for cooling. For example purposes 1 gallon of water per person per day will be used. For a household of 4 people, 4 gallons of water will need to be treated. Thus an AC treatment device with a 200 gallon capacity will last 50 days (200 gal/4 gal per day).

Performance of AC filters have been reported by Consumer Reports (Nov. 1983), Rodale's Practical Homeowner (Jan. 1987), USEPA from results of tests conducted by Gulf South Research Institute (GSRI) in J. American Waterworks Assoc. (April 1984) and National Sanitation Foundation (NSF) (July 1988). The results that are summarized below are for a limited number of the AC devices to illustrate their performance differences. Table 1 lists a number of AC treatment devices from the GSRI study and Table 2 summarizes AC filters tested by Rodale Press. The organic compounds tested for removal by GSRI were THMs (chloroform, bromoform, dichlorobromomethane, and dibromochloromethane) which are primarily byproducts of chlorination disinfection of drinking water; NPTOC (nonpurgeable total organic carbon) which are predominated by larger molecules whose origins are natural organics that can cause taste odor and color; and halogenated hydrocarbons (carbon tetrachloride, trichloroethylene, tetrachloroethylene, trichloroethane, dichlorobenzene, hexachlorobenzene and chlordane) whose origins are industrial solvents. Table 2 summarizes the percent removal of each of these 3 categories during the manufacturers rated filter life. Figures 3 and 4 illustrate the removal efficiency of THMs and NPTOC's as the filter processes water. In all examples the removal efficiency decreases as increased volume of water is processed. Substantial differences do occur.

The results of Rodale Press analysis of AC treatments devices (Table 2) were published for chlorine, halogenated organics (72 of USEPA's 129 priority pollutants, the tested organics not defined) and taste. These results are listed in Figures 5, 6 and 7 for the rated filter life capacity. The percentage removal of halogenated organics was the total removed and does not differentiate between specific chemicals. No chemical specific removal percentages were listed.

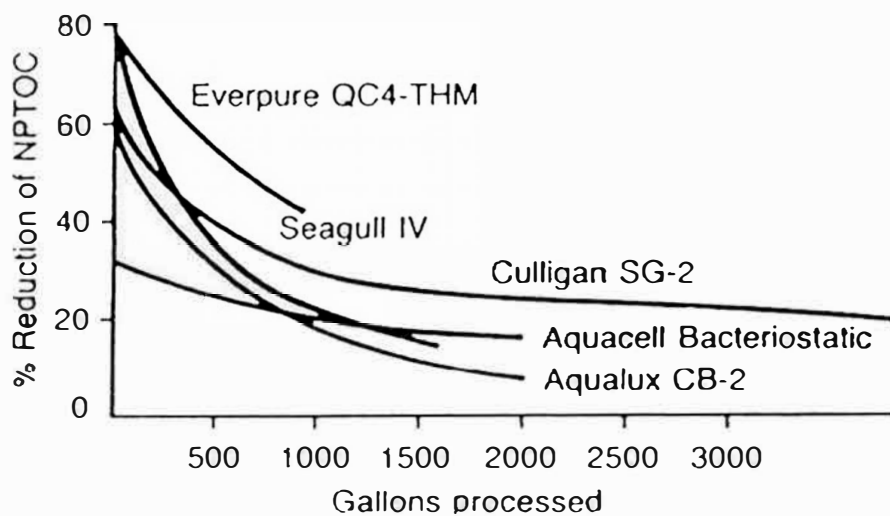
The NSF reports the validation of claims by drinking water treatment device manufacturers if these units are submitted voluntarily for testing and meet the standard set out by NSF. The NSF has standards to assess claims for aesthetic effects (Standard #42) of drinking water devices. Aesthetic effects pertain to factors affecting drinking such as taste, odor, color and

Figure 3. THM Removal Efficiency For GSRI Study for USEPA



\* THM - Tri Halo Methanes

Figure 4. NPTOC Removal Efficiency for GSRI Study for USEPA



\* NPTOC - Nonpurgeable Total Organic Carbon

Table 2. Rodale Tests of

# ACTIVATED CARBON WATER FILTERS

TYPE	MANUFACTURER	MODEL	COST	FILTER MODEL	FILTER COST	FILTER LIFE GALLONS (AS TESTED)	AMOUNT OF CARBON (GMS)
Under Sink Separate Faucet	Astropure	AP10	\$240	AP10C	\$60.00	2,000 gal.	474.2
	General Ecology	Seagull IV X1-F	300	RS-1S6	44.95	1,000 gal.	338.7
Cartridge	Ametek	CSL-GAC10	28	GAC-10	8.50	1,200 gal.	327.0
	Filterite	CF-10	75	IC-11	11.95	750 gal.	345.0
End of Faucet Counter Top (Bypass)	Rush Hampton	Ecologizer #5505	30	#5525	9.95	1,000 gal.	205.2
	Neolife	Water Dome #500-32	150	#34	32.95	500 gal.	354.9
End of Faucet (Bypass)	Aqua-Guard	AGT300	30	T30XL	3.50	400 gal.	56.6
	Pollenex	Pure Water 99 WP100	33	FWP100	4.95	250 gal.	40.0
Pour Through Appliance	Filter Cold	Filter Flask	30	N/A	N/A	600 gal.	125.9

Prices as of April 1985—may vary or be discounted

Water Treatment System	Percentage of Bacteria Removed
SEAGULL IV	100
WATER DOME	100
FILTER FLASK*	100
ASTRO-PURE	100
FILTERITE CF-10	90
AMETEK CSL-GAC10	90
ECOLOGIZER	65
PURE WATER 99	55
AQUA-GUARD	50

Water Sample	Relative Toxicity (approx.)
WATER DOVE	75
PURE TREATING	65
SEA DULL IV	65
WATER TREATING	62
ASTRO PURE	55
PURE FLASK	53
PURE WATER 99	48
ECOLOGIZER	42
WATER GUARD	40

1

Figure 7. Rodale Test  
RESULTS OF TASTE TEST

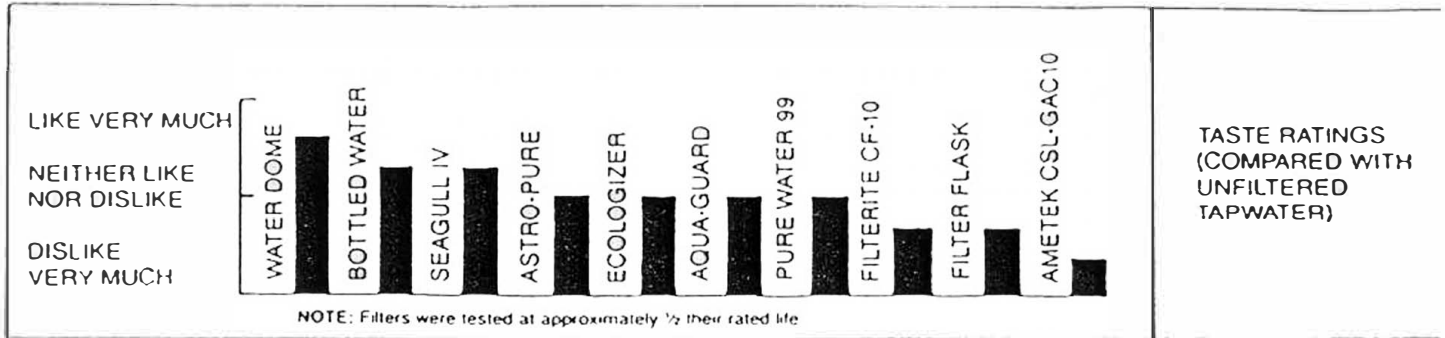


Figure 8. National Sanitation Foundation (NSF) Certification Mark

appearance. The effluent from these treatment devices must meet the USEPA Secondary Drinking Water Regulations while processing the water up to the rated capacity of the device. These regulations are for chemicals that affect taste, color, odor and appearance. The devices are challenged with a standard prepared water (chemical components exceeded the recommended secondary concentrations) to substantiate the claims. The devices are required to be periodically tested to certify that they continue to meet the claims. Those devices meeting Standard #42 are allowed to use the NSF Mark (See Figure 8) on the device the literature and advertising. Further NSF evaluates bacteriostatic devices designed to limit the passage and/or growth of heterotrophic bacteria under Standard #42. It requires that the bacterial population is no greater in the effluent from the device than in the influent. NSF tests whether the active bacteriostatic agent or its degradation product in all effluent samples does not exceed the USEPA Primary Drinking Water Regulations or those of any other Federal regulatory agency for chemicals not regulated by USEPA.

NSF also has established a standard (Standard #43) for assessing and certifying drinking water treatment devices that claim the reduction of chemicals in drinking water that are hazardous to health, i.e. those chemical that exceed the USEPA Primary Drinking Water Standards or those chemicals that are suspected of adverse health affects but no USEPA standard has been established. The use of the NSF Mark is the same as in the previously explained standard. The NSF publishes a book semi annually listing those devices that currently meet the Standards #42 and #43 for claimed drinking water quality improvements.

Radon gas dissolved in water can be removed using AC. AC can remove 99% of the radon. No tests have been published concerning radon removal efficiencies concerning commercially available drinking water treatment devices.

There are several drawbacks of AC units. Since AC deactivates chlorine, bacteria present in the AC will not be affected by the disinfecting action of chlorine and are free to proliferate and grow. Studies have indicated that if the influent water to the devices are pretreated to eliminate pathogenic (disease causing) bacteria, no pathogenic bacteria will grow and multiply on the AC. But non pathogenic bacteria, in particular heterotrophic plate count (HPC) bacteria, will grow. If water has not passed through an AC filter overnight, these bacteria will grow. Then the first drawn water from the filter in the morning will be cloudy with bacteria flushed from the AC device. A 30 second flushing of filter at full flow reduces the HPC bacteria counts to 1/7 the initial effluent numbers and as AC filter is used intermittently over 4 hours (during a normal household activity period), the HPC bacteria are reduced by 1/25. But several studies still indicated that the HPC bacteria in effluent is higher than influent HPC bacteria counts. The health concerns of high counts of HPC bacteria is not clear. We ingest millions of bacteria per day normally with no ill health side effects. But health officials

generally are not concerned about HPC bacteria ingested by healthy individuals. A potential health problem may be with those that are more vulnerable. The aged, the very young or the sick are more vulnerable because their immune systems are weaker. Certain HPC bacteria are known to be "opportunistic" and may take advantage of these weaknesses and cause an illness.

Manufacturers have produced AC with impregnated silver to prevent HPC bacterial accumulations. The silver is a disinfectant and when released or leached from the AC in small quantities is supposed to interact with the bacteria in the AC filter and reduce their ability to increase in numbers. The silver, a heavy metal is to be released in small enough quantities so as not to exceed the toxic limits set forth by the USEPA Primary Drinking Water Regulations. These type filters are called bacteriostatic filters and must meet requirements previously mentioned.

Studies by the GSRI for the USEPA have indicated that silver impregnated AC made little difference when compared to untreated AC in terms of HPC bacteria growing on the AC or in total counts found in the effluent water. The best recommendation for prevention of high HPC bacteria counts is to replace the AC filter periodically based on manufacturers recommendation of use time (days or months) or even more frequently. If no recommendation is made by the manufacturer, replace the AC at least every 6 months (maybe even every 3 months) even if the manufacturers recommended treatment capacity is not exceeded.

The other disadvantage of an AC filter is that the only certainty that the AC filter has reduced the contaminant of concern is to test the effluent water. If the contaminant is only an annoyance such as a taste, odor, or color; then when the AC filter is not longer effective health is not at risk. The consumer will be aware of the loss of its effectiveness. But many hazardous chemicals have no detectable "off" tastes, odor or color to the consumer.

#### Recommendations to the Consumer

- Use AC filters on microbiologically safe water (disinfected water).
- Use AC filters on cold water only.
- Watch for signs of sediment in effluent and replace AC filter.
- A change in taste, odor, or color can mean the breakthrough has occurred i.e. when the AC is no longer effectively removing the compounds, replace the AC filter.
- When the effluent water from AC is noticeably reduced, replace the AC filter.
- Filter water at slowest possible rate tolerable. This increases contact time.



- Flush out filters when first used each day for 30 seconds. Flush for longer periods of time if not used for several days.
- Change the AC filter as frequently as recommended by the manufacturer -- preferably more often.

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